

FRESHMAN DESIGN IN CHEMICAL ENGINEERING

At Rose-Hulman Institute of Technology

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Freshman Design or Freshman Engineering has become an integral part of engineering education, but the format of the course varies significantly from one program to another. This paper discusses the Freshman Design course in Chemical Engineering at Rose-Hulman Institute of Technology (RHIT). While freshmen attend a very general “Introduction to Engineering” course at some institutions, RHIT students have already selected their major when enrolling in the freshman engineering class (Introduction to Design). Each section of the class is designated as being for a given major. This provides two benefits in particular: 1) the “competition” between engineering disciplines often associated with freshman engineering courses is eliminated by this early declaration of their major, and 2) the group of students is focused on a common interest in chemical engineering in particular rather than on engineering in general. This allows the instructors to directly introduce basic chemical engineering and process design concepts at the freshman level to give students a better overview of what lies ahead.

Since chemical engineering is a challenging area of endeavor, the freshman design course is designed as a challenging experience. The primary student-learning goals of the course include developing an understanding of how basic science and mathematics interface with engineering, fostering an awareness of the chemical engineering curriculum as well as careers available to chemical engineers, developing and improving communication and teaming skills, and creating a realistic view of practicing chemical engineering (see Table 1). For a class that meets two hours a week for ten weeks, this is a challenging list of goals (for both faculty and students)! The project-based approach is used to achieve the learning goals.

We will describe how a project, based on the preliminary design and economic analysis of a chemical plant, is used to achieve four of the five goals (see Figure 1). The project is used to introduce concepts such as the steps of process design and the connectivity of math, science, and engineering, to promote a more thorough awareness of the curriculum and the relevance of each of the required courses, to further develop teaming and other soft skills, and to encourage the proper documentation

TABLE 1
Course Goals

- Expand the students’ knowledge of the various areas of endeavor available to chemical engineers.
- Develop the students’ understanding of how basic science and mathematics interface with engineering.
- Increase the students’ awareness of the chemical engineering curriculum and core competencies.
- Develop, extend, and improve the written and oral communication and teaming skills of the students.
- Present the students with a realistic view of practicing chemical engineering.

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of technical work.

In 1990, Professor Emeritus Carl Abegg created a controlled-release nitrogen fertilizer plant-design problem and the basic project content to remedy what he, and our freshmen, felt was an unsatisfactory experience in freshman design. He had been actively involved with the design of a production facility based on the process in the disclosed patent^[1] that is used in the course.

The department has continued using the project, making modifications and varying emphasis to the process each year. It has been taught by Professors Carl Abegg, Jerry Caskey,

Atanas Serbezov, and myself. Professor Serbezov and I currently teach two sections each of the course, with an average of approximately 15 students per section.

The course design and approach have changed with each year and each instructor. This paper describes the results of the course's evolution and reflects the author's current style of instruction.

THE PROJECT

One challenge instructors face is to find a process that is appropriate for freshmen. Very few process operations can be presented with sufficient detail at an introductory level. Since some of the primary operations in the process used in our course are mixing and drying, the project is quite suitable for introduction at the freshman level. These concepts are familiar to the students from their personal experiences—for example, mixing water, tea, and sugar in a glass or using a blender to make a milkshake are common “mixing” processes. Moreover, blow drying hair or drying clothes in a dryer (provided they are not still taking their laundry home for Mom to do) are familiar “drying” processes. While these concepts are readily grasped by a freshman, distillation or gas absorption would be very difficult to present in sufficient detail without background knowledge the students will attain in the sophomore and junior core courses.

The simplified process used in the course is based on an expired patent,^[1] which the students actually read. This gives them an opportunity to experience the differences between “textbook” writing and the writing in a formal patent. By discussing the legal implications of actual design documents, the students become more aware of the need to properly document their work. It is also an opportunity to introduce the career option of patent law.

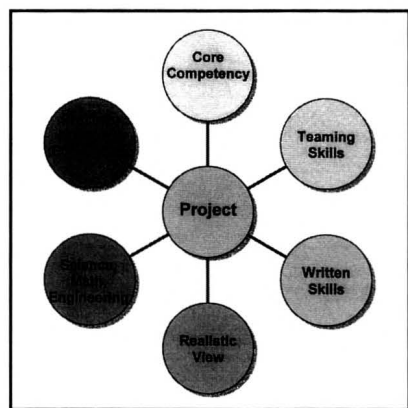


Figure 1. The project is the focal point of the course.

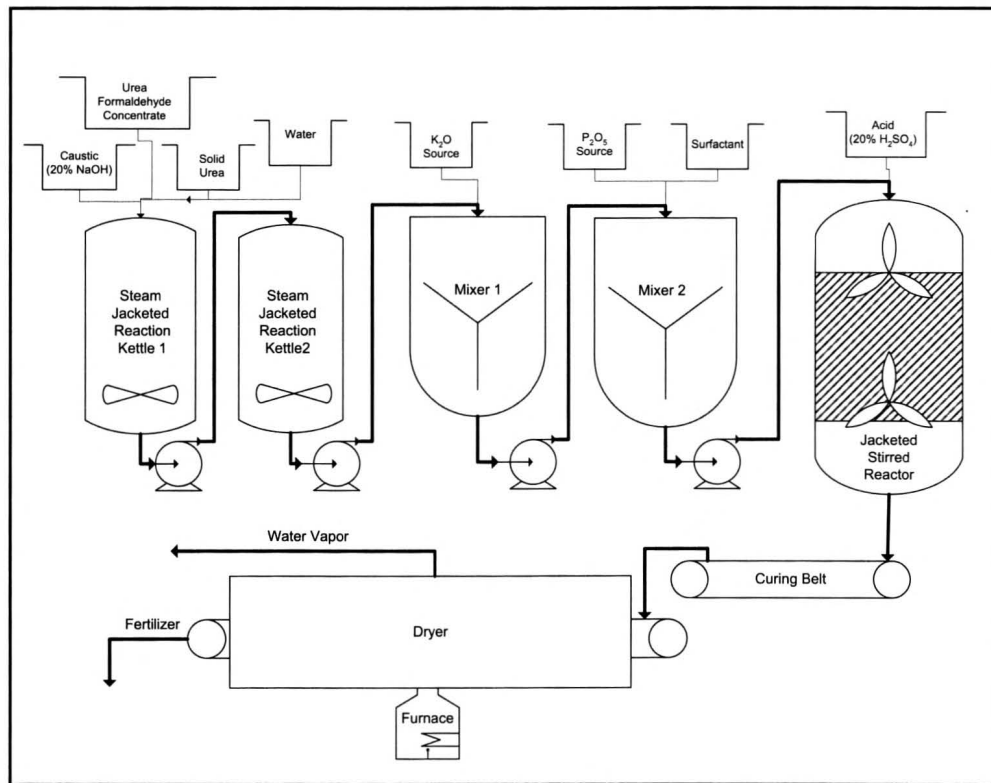


Figure 2. Simplified process schematic.

The primary pieces of equipment in the operation, depicted in Figure 2, are reaction kettles, mixers, a stirred reactor, a curing belt, and a dryer. After they have read the patent, an in-class brainstorming session is held and the students are asked to indicate what information is needed to design the plant. Questions such as “How much do we want to produce?” and “What is the amount of raw materials needed?” to “How much steam should be supplied?” and “Do we need to maintain a specific pH or temperature?” are generated by the students and listed on the board. We then map this information to the required courses in the chemical engineering curriculum. A sampling of students’ answers and the mapping is given in Figure 3. Although they may not yet realize drying is a “mass transfer”

operation or that the study of heat transfer is needed to fully design a reaction kettle, these points are made during the class discussion in addition to other connections that encompass the entire core curriculum. This addresses part of the third goal for the course.

At this time we further emphasize the complimentary nature of the fields of chemistry and chemical engineers. Through using examples such as new drug development or the discovery of a novel polymer, the differences in the work of a chemist conducting a bench-scale study and a chemical engineer performing a pilot plant investigation and full production are discussed.

The students need to realize the significance of basic chemistry knowledge to their success as chemical engineers. For example, a one-to-one mole ratio reaction occurs in the first reaction kettle. In the stirred reactor, an acid catalyzed polycondensation reaction is initiated. By adding acid to this reactor, a neutralization reaction also occurs with the caustic that was added upstream to the first reaction kettle. By specifically including the reaction chemistry, the students immediately grasp the relationship between the two fields and their true complimentary nature. This addresses the second goal.

PRELIMINARY DESIGN

The preliminary design of the process allows us to address a variety of core competencies (Goal 3), beginning with introduction of the laws of conservation of mass and energy. Material balances are performed to determine the amount of

raw materials needed to produce a set amount of fertilizer of a particular composition. Energy balances are used to determine the amount of steam at a specified pressure needed to supply heat for the endothermic reaction that occurs in the first kettle. We also ask the students to determine the amount of natural gas needed to be supplied to the dryer for a given efficiency of the dryer. Typically we ask them to size the reaction kettle and either the curing belt or dryer based on density information and/or desired moisture content of the final product. Some of the variables that can be modified from year to year include the pieces of equipment sized, the production rate, the fertilizer composition, and variations in the emphasis on certain aspects of economics.

In addition to the use of material and energy balance concepts, the students begin to understand the role of chemical reactions and how it affects other principles. For example, since the polycondensation and neutralization reactions both produce water, this additional water must be taken into account when determining the amount of water that must be evaporated in the dryer to achieve the desired moisture content and production rate.

We sometimes give students insufficient information, which means they have to use steam tables or find information in the literature. An added benefit of using the literature is that it requires the students to actually visit the library to find the needed information, and when reading the literature they are forced to use their "engineering judgment" to determine the most appropriate information. For example, as part of their

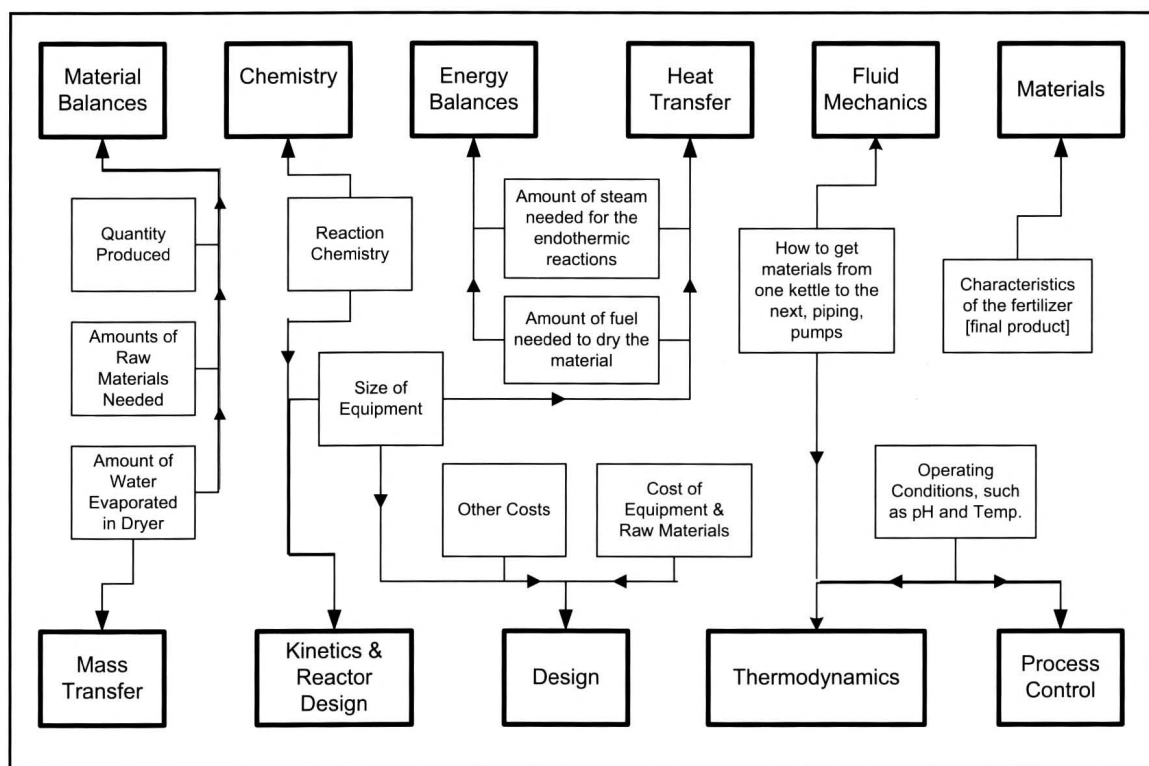


Figure 3.
Mapping of student ideas to the curriculum.

economic analysis, we require that the students use the *Chemical Market Reporter* to find current cost data for the raw materials. Sulfuric acid, which is used in this process to catalyze the polymerization reaction, is listed as 100% whereas our process calls for 20 wt%. This requires the students to actually think about the proper way to use the information they find, as opposed to the plug-n-chug approach that many students entering college are accustomed to. As a result, they discover that not all the information needed to solve a problem will be available in the “back of the book.” Our hope is that by requiring the use of the library to find relevant information in current literature early in their educational development, students will continue to use the technique throughout their lives. (Goals 2, 3, 5)

After the actual process, as depicted in Figure 2, is presented to the students and a discussion is held regarding fertilizers and how and why they are important to society, the idea of design as a systematic process with explicit steps is introduced. For example, all design ultimately begins with identification of a need, definition of the problem, and a search for relevant information.

The class members make a list of potential sources of information, ranging from published works to operators in the plant. The iterative nature of the design process is noted. For instance, once the constraints (such as a budget or available land) are established and the product criteria is determined, a need for additional research or refining the problem definition may be necessary.

Realizing that various solutions to the same problem are possible gives rise to a discussion of the weighting of constraints and criteria as part of the decision-making process. We reiterate the idea of design as a systematic process at various stages, including near the end of the course when we review what we’ve accomplished. (Goals 3, 5)

PROJECT ECONOMICS

The economic analysis component of the project affords the students opportunities to make decisions, using their engineering judgment, regarding the cost of various aspects such as raw materials and utilities, labor costs, supervisory costs, and type of processing (fluid, fluid-solid, solid), and to notice how these connect to the total product cost. The ratio factors based on delivered-equipment cost are used to determine the fixed and total capital investment.^[2] The students use a variety of

graphs and charts to size and cost the equipment and to determine the number of employee hours needed based on the number of processing steps. They are given cost information for one capacity and apply the 0.6 power law in order to scale the known information to the project conditions. They make use of the up-to-date Marshall & Swift Cost Index as published in *Chemical Engineering* to estimate current cost using older data. Throughout this project, we introduce the students to many of the concepts needed for a preliminary design, which aids in their understanding of the real-world decision process. (Goals 3, 5)

SOFT SKILLS

As the ideas needed to analyze the project progress, we incorporate various additional “soft skill” items (Goal 4). For example, we require the students to work in teams during the last half of the quarter. Usually one week before they select team members, we ask the students to silently brainstorm characteristics of a “good” team (a team they would like to belong to) and those of a “bad” team (a team that they would not want to belong to). The instructors and/or students then list these characteristics on the board or on an overhead, and we discuss the potential impact of these traits on selecting team members and on team performance.

We introduce the students to the four stages of team dynamics: forming, storming, norming, and performing^[3] and provide them with sample meeting agendas and minutes, along with tips on building consensus. We then ask them to formally submit at least one set of meeting agenda and minutes along with the documented outcomes, such as a timeline, deployment chart, and/or a Gantt chart. By indicating how they have divided their work and the timeline that they set to complete the project, the students are introduced to more effective ways of operating within a team setting, time management, and project management (Goal 5). Since the report is a team effort, it is important that the students have a common framework to which they can refer for timing and responsibilities.

Throughout the quarter, we stress the importance of proper documentation of technical work with the weekly problem sets. The students must submit a formal written report detailing the entire analysis along with their conclusions. The report is a team effort (Goal 4). Additional optional activities include the preparation and presentation of a poster or building either

TABLE 2
The Classroom and the Practicing Engineer

Multiple solutions	◀▶	Engineering judgment
Role of the market	◀▶	Economics must be considered
Working in teams	◀▶	Systematic approach to problem solving
Written communication	◀▶	Communicating with peers and supervisors
Problem solving	◀▶	Presenting work in logical steps for others to follow
Time management	◀▶	Information must be sought from new sources
Project management	◀▶	Summarizing results in project report

a partially working or nonworking model of the process.

Students are also exposed to the role of the market for the particular product. We discuss the effects of competitors in terms of “What do they have that you don’t?” or “Can you offer a ‘better’ product than anything already on the market?” We ask the students to make recommendations regarding further pursuit of the project based on their preliminary design and the market conditions. The effect of the competitors’ prices must be directly considered in this evaluation. We introduce the concept of supply and demand in terms of

questions such as, “Is the market demand such that you can sustain a long-term reasonable share in the market?” (Goal 5) Some of the ways in which the classroom mimics the environment of a practicing engineer are summarized in Table 2.

GOAL 1: CAREER OPTION AWARENESS

While the project (see Figure 1) is the focal point for meeting Goals 2-5, the first goal is approached in such a way as to serve as the introduction to the project. On the first day of class, we ask the students to brainstorm ideas of where in our

Select all that apply.

- Consensus
 - involves discussing of the issues
 - is a unanimous or majority vote
 - means that everyone agrees to support the decision
 - involves clarification and prioritizing
 - means that everyone gets everything they want
- The steps of the design process include
 - Direct charges
 - Identification of a need
 - Constraints, such as cost or time
 - Maintenance
 - Steam Tables

Fill in the blank.

- A material balance is a statement (or an application) of the law of conservation of mass.
- Storming is a stage of team growth or team dynamics in which the group members are in a state of panic, often characterized by each member working independently rather than together.

Short Answer

- List 3 advantages of working in a team.

Part II: Problems.

- A plant is to be designed to produce a slow release fertilizer with analysis of 30-12-10. MAP with an analysis of 13-52-0 is to be used as a phosphorous source and KCl with analysis of 0-0-60 is to be used as a potassium source. Fertilizer grade urea with analysis of 45-0-0 will be the primary nitrogen source. UFC with composition 60 wt% formaldehyde (H₂CO), 25 wt% urea and 15 wt% water will be the formaldehyde (H₂CO) source. A partial list of the raw material amounts to be used is shown in the table below:

Raw material	Amount (lb/hr)
MAP	6,923
KCl	5,000
UFC	6,400
Solid Urea	
Water	1,690
Surfactant	112
H ₂ SO ₄ (20%)	1,250
NaOH(20%)	95

 - What is the fertilizer production capacity (in lb/hr) for this plant? A periodic table is attached at the end of the handout. If you cannot solve this part, use a value of 25,000 lb/hr to continue the problem. (25,000 lb/hr is **not** the correct answer.)
 - What is the required amount of solid urea (in lb/hr) for this plant?
 - Find the amount (in lb/hr) of steam at 50 psi needed to supply the necessary heat for the methylol urea reaction if it is known that the efficiency of the heat exchanger is 75 % and the methylol urea reaction consumes 23,500 BTU per lbmole of methylol urea produced. A steam table is attached at the end of the handout.
 - What is the amount of water (in lb/hr) produced in the reactor as a result of the chemical reactions? You **do not** need to write the reaction chemistry or to explain it in detail.

Figure 4. Sample exam questions.

society chemical engineers play a role or influence the society in some way. A “cartoon” depicting items such as paint cans, gasoline pumps, plastic containers, and space ships is sometimes used as the springboard for this discussion. This introduces some of the more traditional career paths for chemical engineers such as the process engineer at chemical, plastics, or petrochemical plants. Students jump readily from traditional areas to some of the cross disciplines, such as environmental concerns, giving us an opportunity to talk about careers in environmental firms, OSHA, or other regulatory agencies. Pharmaceuticals, an area of strong interest in our area due to the nearby Eli Lilly and Pfizer plants, is always mentioned by the students, allowing us to further bring into the discussion the cross-disciplinary nature of the field. We introduce the various minors and areas of concentrations available in the curriculum, including biomedical, biochemical, environmental, chemistry, semiconductors, polymers and plastics, and a certificate in engineering management. This initiates thinking “outside the box” for potential careers and provides an opportunity for the students to use foresight in preparing their plan of study in order to incorporate specific areas of interest.

One additional area of focus is the role of professional societies. We strongly encourage the students to become active members of AIChE and at least one other professional society, such as SWE, ISPE, NSBE, ACS, or AXE. We stress the many benefits of membership such as networking, introduction to various companies through talks hosted by the societies, exposure to a wider range of ideas and applications through the membership journals, etc.

One of the most important ideas presented to the students during this course results directly from their introduction to the professional societies—the engineering code of ethics. Every year we present the engineering code of ethics, either from NSPE or AIChE, to the students. We discuss some of the ways in which the code applies in their life today, such as honesty and integrity. We then ask them to submit as a homework assignment how they will apply each area of the code of ethics during their undergraduate career.

ASSESSMENT

The degrees to which the goals for the course are met are assessed based on a set of student learning objectives that describe the concept that is to be mastered and how that mastery will be measured. The course assignments, ranging from the weekly homework assignments to the final project and course exam, are mapped to these learning objectives to verify that each objective was assessed appropriately. A few sample questions from a recent exam are presented in Figure 4. The types of questions range from “short answer” and “fill in the blank” to challenging problems. Also, a questionnaire for seniors is currently being developed to assist in analyzing the effectiveness of the course in pro-

moting learning in subsequent courses.

SUMMARY

The course gives students a realistic taste of what it is like to be a practicing chemical engineer and what it takes to become one. Students are given a project that deals with the preliminary design and economic analysis of a chemical plant. Through various homework and class assignments they are required to apply the steps in engineering design, to participate in team assignments, and to solve open-ended problems where answers are obtained over weeks instead of minutes. They work on the project individually and in groups under the supervision of the faculty instructor. These open-ended problems involve applying engineering constraints, making approximations and engineering judgments, and using teaming skills as well as communicating the results through a formal written report.

In their class activities, students emulate practicing engineers, which keeps their interest and motivation high despite the various challenges. At the end of the course, they have a much clearer focus and understanding of what lies ahead of them, not only in their undergraduate career but also in the initial years as a practicing engineer.

By using the project-based approach with an actual chemical process design, students are better able to grasp the basics of chemical engineering and improve or develop teaming and communication skills. Most students find the project challenging and develop a better understanding of the profession and the curriculum. They leave the course with a sense of accomplishment and pride having completed a “real” project.

ACKNOWLEDGMENTS

Professor Emeritus Carl Abegg created the controlled-release nitrogen fertilizer plant-design problem and the basic project content in 1990. Professor Emeritus Jerry Caskey continued to use the project after Carl’s retirement. Professor Abegg is thanked for his helpful discussions regarding the course and its content. The many discussions with and input from Professor Serbezov regarding the course are greatly appreciated. Professor Robert Sauer and Mr. Samuel Bunch are acknowledged for their suggestions to improve the manuscript. Mrs. Mary Wade contributed to the design of Figure 3. Parts of this work were presented at the ASEE 2003 Annual Meeting under a similar title.

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